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Topside investigation over Cyprus and Russia using Swarm data

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Abstract

Using topside electron density measurements (Ne) recorded over Nicosia (geographic coordinates: 35.14°N, 33.2°E) and Moscow (geographic Lat: 55.50 °N, Long: 37.30 °E) we investigate the latitudinal variation of topside electron density during 2020 encompassing a period of low solar activity. The selected topside electron density dataset employed in this study is based on in-situ Langmuir probe data on board European Space Agency (ESA) Swarm satellites, in the vicinity of Nicosia and Moscow combined with coincident NmF2 values from the Digisondes at the two locations. Our investigation demonstrates that the ratio Ne/NmF2 between coincident Swarm Ne and Digisonde NmF2 observations is higher than 1 on some occasions over Nicosia during nightime which is not the case over Moscow signifying a latitude based feature of Ne at Swarm altitudes worth exploring further.

1 Introduction

The ionospheric altitude range above the peak height of F2 layer and below the upper transition height corresponds to the topside ionosphere which contributes significantly to the total electron content (TEC) so it is mandatory to study its morphology using various measurement techniques. Although ionosondes is the principal technique for bottomside ionospheric monitoring it is impossible to study the variability and structure of topside ionosphere with vertical sounding because they can only probe up to the peak height of F2 layer so alternative approaches such as satellite topside sounders are necessary to monitor the topside ionosphere electron density profile. However the lack of satellite topside sounders which would be the ideal method to monitor topside ionosphere electron density, Langmuir probes (LP) on board low Earth orbit (LEO) satellites facilitate in-situ electron density measurements that have been incorporated on several present and past satellite mission payloads [1-5]. During the last decade a number of researchers have carried out comparison studies of satellite based LP data with alternative topside probing techniques [6,7].

Three identical satellites constitute the Swarm mission that is set in near-polar, circular orbit by the European Space Agency (ESA) since 2013 with a primary scientific focus on the study of the magnetic field of our planet. During the early stages of the mission all three satellites were flying at an altitude of 500 km. Later, Swarm A and C were shifted at 460 km while maintaining a longitudinal separation of about 1.4° and Swarm B to an approximate altitude of 530 km. A primary instrument on all three satellites is an Electric field instrument (EFI) [8], which records measurements of plasma density, velocity and drift at a high resolution. The EFI carries a pair of Langmuir probes (LP) that measure the in-situ electron density, electron temperature and electric potential from the high gain probe at 2 Hz. Comparison studies incorporated Swarm data and collocated Digisonde soundings for local bottomside and topside ionospheric studies [9].

2 Data

In this study, we exploit Swarm A and B topside electron density passes over the longitude range within 2° of Nicosia and Moscow and simultaneous Digisonde F2-layer peak electron density measurements NmF2 over the two stations of Nicosia and Moscow to investigate the temporal features of the ratio Ne/NmF2 over the two locations.

Regarding the quality of Swarm electron density (Ne), the Ne Quality flag (≤29) and the Ionospheric Plasma Irregularities (IPIR) index (<3) has been chosen as per Swarm L2 product specifications guidelines. Digisonde NmF2 values at the altitude of the Swarm satellites were considered at a maximum of 7.5 min from any Swarm A or C passage over Cyprus.

Figure 1 shows an example of a Swarm A pass over the two stations and the corresponding longitude electron density profile at an altitude of 460 km. By selecting an appropriate longitude range within 35°–56° in latitude and 32°–38° in longitude we have gathered a considerable number of such passes in the vicinity of the two stations (within 0.5° in latitude and 2° in longitude) for year 2020 which was at the lowest solar activity level of the previous solar cycle. These numbers were sufficient to draw some interesting conclusions regarding topside electron density at Swarm altitudes by exploiting the accuracy at which NmF2 is measured by Digisondes.

Table 1. Number of electron density values in the vicinity of the two stations from the joint passes over the common longitude range.

Station Name	Number of points for SWARM A	Number of points for SWARM B
MOSCOW	122	124
NICOSIA	124	117

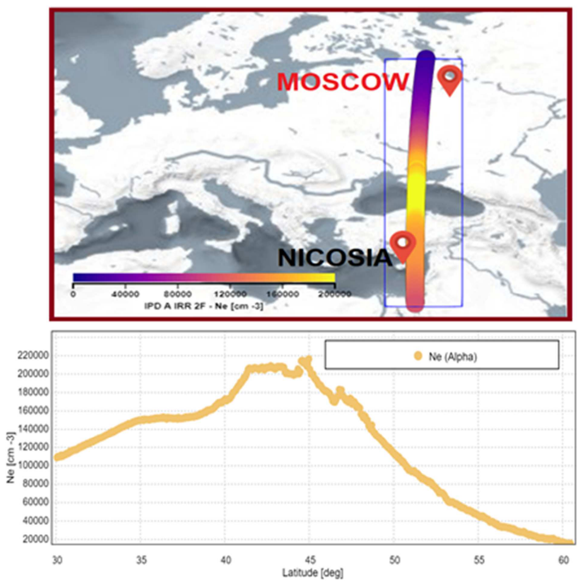

Figure 2. Swarm A projection and corresponding Ne variation vs latitude.

3 Results and Discussion

Figures 2 and 3 show the local time variation of the ratio of Ne_Swarm/Digisonde NmF2 (Ne/NmF2) for all passes considered for Swarm A and B over Moscow and Nicosia respectively. Ratios corresponding to Swarm A and Swarm B are indicated in red and green respectively. It can be seen from these graphs that for the low solar activity year of 2020 the ratio Ne/NmF2 is less than 1 during daytime and increases during night-time (0-4 LT & 20-24 LT) reaching values up to 1.5 for Nicosia station as indicated in Figure 3. This is a very interesting finding since Ne/NmF2>1 indicates that topside electron density can exceed the peak electron density of the F2 layer over Nicosia during night-time, which is rather unexpected.

The enhancement in Sx/C during nightime shows that Swarm satellites occasionally exhibit dramatically higher Ne values which contradicts theory. These higher value of Swarm Ne may correspond to the long lasting latitudinal four peak structure in the nighttime ionosphere observed by the Swarm constellation. Xiong et al., (2019) have studied the four peak structure in the night-time ionosphere and they have reported that two mid latitude peaks appear close to ±40° magnetic latitude, while the two low latitude peaks appear within ±20° magnetic latitude. Such latitudinal four peak structures can persist throughout the night until sunrise hours. No clear seasonal dependence is found for the two mid latitude peaks, while the two low latitude peaks are almost symmetric about the magnetic equator during equinoxes but are located at slightly higher latitudes in the summer hemisphere around solstices [10].

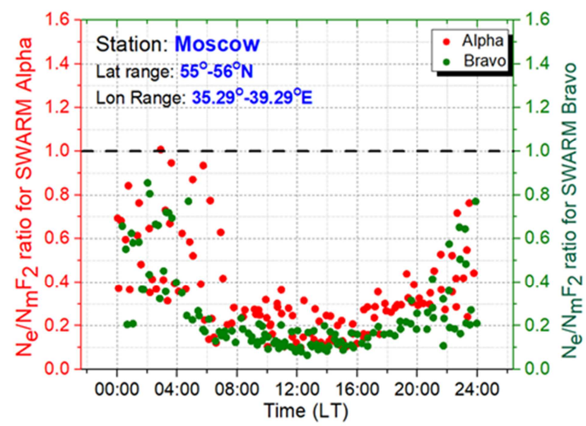

Figure 2. Variation of Ne/NmF2 over Moscow with respect to local time for (a) Swarm A (red points) and (b) Swarm B (green points).

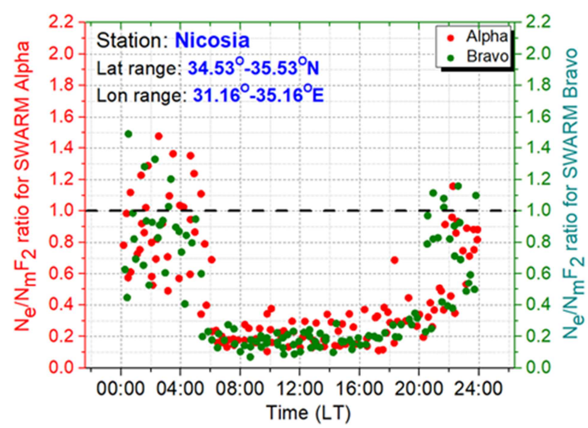

Figure 3. Variation of Ne/NmF2 over Nicosia with respect to local time for (a) Swarm A (red points) and (b) Swarm B (green points).

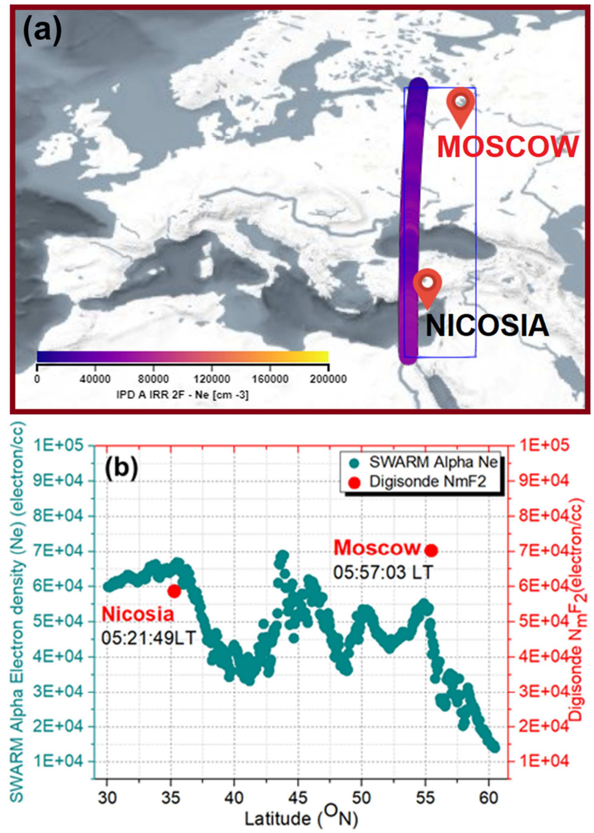

Figure 4. Swarm A projection and corresponding Ne variation vs latitude with superimposed NmF2 values over Nicosia and Moscow.

Figure 4 shows an example of the variation of electron density at Swarm A altitude (465 Km) with values of NmF2 over the locations of Nicosia and Moscow. This example is typical of the cases shown in Figures 3 and 4 for which night-time Ne/NmF2 ratio over Nicosia exceeds 1 and the corresponding ratio over Moscow is less than 1. Although during night-time it is expected for this ratio to be higher than daytime since hmF2 increases, approaching Swarm altitude, a value higher than 1 and especially as high as 1.5 is not reasonable and unexpected. In this study, we have also tried to use topside electron density data around to compare with Swarm A or B electron density around the same time and area, considering the fact that radio occultation (RO) profiles under specific criteria can provide accurate topside electron density information [11]. However no RO profiles were available over the area of interest at the time of the storm development.

4 Conclusions

This study demonstrated that the ratio Ne_Swarm/Digisonde NmF2 exhibits latitudinal changes and also a local time effect due to the smaller background density at nightime. The main finding of this regional focuses on the extraordinary values of Ne_Swarm during night-time, which could be attributed to the long lasting latitudinal four peak structure in the nighttime ionosphere observed by the Swarm constellation. Although quiet time TEC increases have been reported over Nicosia during low solar activity years we can not justify the excessive Ne_Swarm on NmF2 increases since we have to consider relative changes would be reflected both on Ne at the topside and NmF2 [12,13].This will be further explored in the near future by extending this investigation to a more extended geographical scope.

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